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QUERCUS POLLEN SEASON DYNAMICS IN THE IBERIAN PENINSULA: RESPONSE TO METEOROLOGICAL PARAMETERS AND POSSIBLE CONSEQUENCES OF CLIMATE CHANGE

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Abstract: The main characteristics of the *Quercus* pollination season were studied in 14 different localities of the Iberian Peninsula from 1992-2004. Results show that *Quercus* flowering season has tended to start earlier in recent years, probably due to the increased temperatures in the pre-flowering period, detected at study sites over the second half of the 20th century. A Growing Degree Days forecasting model was used, together with future meteorological data forecast using the Regional Climate Model developed by the Hadley Meteorological Centre, in order to determine the expected advance in the start of *Quercus* pollination in future years. At each study site, airborne pollen curves presented a similar pattern in all study years, with different peaks over the season attributable in many cases to the presence of several species. High pollen concentrations were recorded, particularly at Mediterranean sites. This study also proposes forecasting models to predict both daily pollen values and annual pollen emission. All models were externally validated using data for 2001 and 2004, with acceptable results. Finally, the impact of the highly-likely climate change on Iberian *Quercus* pollen concentration values was studied by applying RCM meteorological data for different future years, 2025, 2050, 2075 and 2099. Results indicate that under a doubled CO_2 scenario at the end of the 21st century *Quercus* pollination season could start on average one month earlier and airborne pollen concentrations will increase by 50% with respect to current levels, with higher values in Mediterranean inland areas.

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INTRODUCTION

In spring, tree pollen grains of the Fagales order which includes *Quercus* genus, are a main allergen source in the northern hemisphere, with cross-reactivity occurring between pollen within the same order [40, 44]. Several studies consider *Quercus* pollen type responsible for allergy in areas with abundant *Quercus* vegetation [5, 38,

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46, 52, 56, 57]. The *Quercus* genus is represented in the Iberian Peninsula by 11 tree species commonly known as oaks (cork-oaks, holm-oaks, gall-oaks, etc.). These species are distributed throughout the entire peninsula, are well represented in Atlantic forests and dominate most Mediterranean ecosystems. All are anemophilous trees producing stenopalynus pollen grains (not distinguishable under light microscopy) in high quantities that are well dispersed through the air [29, 58]. The high abundance of these species in natural and semi-natural vegetation areas increases allergy risk for agriculture and forestry-related workers in the Iberian Peninsula, highly exposed to *Quercus* pollen grains [56]. *Quercus* pollen season dynamics and their relationship with meteorological factors were studied at 14 sites of the Iberian Peninsula (Spain). Particular attention was paid to the effect of the detected temperature increase in later years on the *Quercus* pollen season, and to the potential consequences of the global climate change.

In recent years, the rise in winter and spring temperatures as a consequence of global climate change is causing earlier leafing and flowering in many species, in both Europe and the USA [4, 17, 41]. Changes in the pollination period features, both timing and intensity, of plants producing allergenic pollen would have important consequences on allergy sufferers [3, 16]. Knowledge and forecasting of the pollination dynamics provides useful information for managing and preventing allergic symptoms. The effect of recent climate warming on vegetation phenology and aerobiology is an important issue which is being taken into account in climate-change studies [28, 53]. Because *Quercus* pollen emission is a springtime phenomenon, pollen season dynamics are sensitive to changes in phenology.

Global average surface temperature has increased 0.6°C since the late 19th century. Spring temperatures in the Mediterranean countries have risen by 2°C over the last two decades [36, 42]. The increase has been shown to prompt earlier leaf bud bursting and flowering in temperate Mediterranean tree species such as oak and olive [24, 27]. The Special Report on Emissions Scenarios (SRES) produced a series of scenarios of CO_2 emissions representing outcomes of distinct narratives of economic development [45]. Scenarios are plausible future states of the climate system. They are derived from predictions of climate change from Global Climate Models (GCMs) based on CO_2 emissions scenarios. GCMs are mathematical descriptions of the physical elements and processes in the atmosphere, oceans and land surface (winds and ocean currents, clouds, rainfall, soils). However, in areas where bio-geography has a significant effect on wheather, scenarios based on global models will fail to capture local details for impact assessment. The best method for adding these details to global models is to use a Regional Climate Model (RCM), essentially a higher-resolution version of a GCM covering a limited area [48]. Simulation RCM can be replicated by using forecasting phenological models, and allows assessment of the potential variation in vegetation dynamics [47]. Here, we examine the potential changes on *Quercus* floral phenology in Spain, indicated by airborne pollen dynamics. We use the findings of recent studies and the models developed in this study to drive them with replicated RCM simulations, in order to explore potential changes in *Quercus* pollen season that could accompany future temperature changes in the Iberian Peninsula.

MATERIAL AND METHODS

Description of study areas. The 14 study sites present different climatic, topographic and vegetation characteristics; some of these are summarised in Table 1. Northwest (NW) Spain is a mild-temperature, rainy area influenced by the Atlantic Ocean. The predominant form of vegetation is deciduous woodland, with a large population of *Quercus* species. Vigo and Santiago are located in the Euro-Siberian region, with similar weather and vegetation conditions and low altitude. *Quercus robur* L. (first in flowering) and *Quercus pyrenaica* Willd. are the most common *Quercus* species in the forests of this area. The remaining study areas are situated in the Mediterranean Region, although Ourense and Leon are highly influenced by the Euro-Siberian region climate. The sampling sites located in the northeast (NE) of the Iberian Peninsula, Barcelona, Tarragona, Lleida and Girona, have a typically Mediterranean landscape, with extensive areas of holm oaks (*Quercus ilex* subsp. *ilex* L., *Quercus ilex* subsp. *ballota* (Desf.) Samp), *Quercus humilis* Miller, and *Quercus suber* L.; Kermes oak (*Quercus coccifera* L.) woodland appears on the most impoverished soils. The climate of the first 2 sites is characterised by the proximity of the Mediterranean sea. Temperatures are warm and annual rainfall is scarce. The phenological flowering order is as follows: *Q. humilis*, *Q. coccifera*, *Q. suber* and *Q. ilex* subsp. *ilex* and *Q. ilex* subsp. *ballota* The Central area has a dry, continental climate with significant inter-seasonal variations in both temperature and rainfall. In the local countryside around Madrid, the dominant *Quercus* species is the holm-oak *Q. ilex* subsp *ballota*, which forms large areas of oak-grass savannahs used for livestock farming and known as *dehesas*. Leon, located to the north, is influenced by the Euro-Siberian region. Its landscape is characterised by mid-altitude holm oak woodland, although higher woodland populated by *Q. pyrenaica* and *Q. faginea* Lam. can also be found. These 2 species flower 1 month later than the holm-oak. The Southern region includes 5 of the study sites: Cordoba, Priego, Jaen, Granada and Malaga This region has a warmer, drier Mediterranean climate, with more moderate conditions in the coastal city of Malaga. Typical vegetation includes *dehesas* of holm-oak (first flowering), cork-oaks (last flowering) in the most humid areas with acid soils, and kermes-oak (second flowering) in impoverished soil areas. A few populations of *Q. pyrenaica* and *Q. faginea* grow in deep ravines and humid locations in the Supramediterranean vegetation area.

Table 1. Site characteristics: geographical setting in the Peninsula, elevation (metres above sea level), coordinates, mean air temperature, average annual rainfall in millimetres, years of analysed data and *Quercus* species present at each site.

Zone	Site	Elevation (m)	Coordinates	Mean air temp. (°C)	Mean annual rainfall (mm)	Years of data (studied period)	*Quercus* species
North-West	Santiago	270	42°53'N, 8°32'W	12.9	1288	9 years (1993-2001)	*Q. robur* (L.) *Q. pyrenaica* (Willd.)
North-West	Vigo	50	42°14'N, 8°43'W	15	1338	7 years (1995-2001)	*Q. robur* (L.) *Q. pyrenaica* (Willd.) *Q. suber* (L.)
North-West	Ourense	130	42°21'N, 7°51'W	13.8	802	9 years (1993-2001)	*Q. robur* (L.) *Q. pyrenaica* (Willd.) *Q. suber* (L.) *Q. ilex* subsp. *ballota* (Desf.) Samp.
North-East	Barcelona	90	41°24'N, 2°9'E	16.5	595	8 years (1994-2001)	*Q. ilex* subsp. *ilex* (L.) *Q. ilex* subsp. *ballota* (Desf.) Samp. *Q. humilis* (Miller) *Q. coccifera* (L.) *Q. suber* (L.) *Q. cerrioides* (Willk. & Costa)
North-East	Tarragona	48	41°7'N, 1°15'E	15.8	478	6 years (1996-2001)	*Q. ilex* subsp. *ilex* (L.) *Q. ilex* subsp. *ballota* (Desf.) Samp. *Q. humilis* (Miller) *Q. pyrenaica* (Willd.) *Q. faginea* (Lamk) *Q. coccifera* (L.)
North-East	Girona	125	41°54'N, 2°46'E	15.0	740	6 years (1996-2001)	*Q. ilex* subsp. *ilex* (L.) *Q. ilex* subsp. *ballota* (Desf.) Samp. *Q. humilis* (Miller) *Q. suber* (L.) *Q. coccifera* (L.)
North-East	Lleida	202	41°37'N, 0°38'E	15.1	385	6 years (1996-2001)	*Q. coccifera* (L.) *Q. ilex* subsp. *ballota* (Desf.) Samp.
Centre	Leon	830	42°34'N, 5°35'W	10.0	550	8 years (1994-2001)	*Q. ilex* subsp. *ballota* (Desf.) Samp. *Q. pyrenaica* (Willd) *Q. faginea* (Lamk)
Centre	Madrid	600	40°27'N, 3°45'W	14.0	440	9 years (1993-2001)	*Q. ilex* subsp. *ballota* (Desf.) Samp. *Q. pyrenaica* (Willd) *Q. coccifera* (L.) *Q. faginea* (Lamk)
South	Cordoba	123	37°50'N, 4°45'W	18.0	600	10 years (1992-2001)	*Q. ilex* subsp. *ballota* (Desf.) Samp. *Q. coccifera* (L.) *Q. suber* (L.)
South	Priego	650	37°26', 4°11'W	14.4	650	8 years (1994-2001)	*Q. ilex* subsp. *ballota* (Desf.) Samp. *Q. coccifera* (L.)
South	Jaen	550	36°46'N, 3°47'W	17.0	582	6 years (1996-2001	*Q. ilex* subsp. *ballota* (Desf.) Samp *Q. coccifera* (L.) *Q. faginea* (Lamk)
South	Granada	685	37°11'N, 3°35'W	15.1	400	10 years (1992-2001)	*Q. ilex* subsp. *ballota* (Desf.) Samp *Q. coccifera* (L.) *Q. suber* (L.)
South	Malaga	5	36°47'N, 4°19'W	18.0	575	10 years (1992-2001)	*Q. ilex* subsp. *ballota* (Desf.) Samp *Q. coccifera* (L.) *Q. suber* (L.)

Airborne data. The aerobiological behaviour of *Quercus* pollen was statistically analysed using a 13-year database (1992-2004) of pollen and meteorological data from 14 sites in the Iberian Peninsula (Tab. 1, Fig. 1). These data were drawn from the Spanish Aerobiology Network (REA) data bank held at the REA Coordinating Centre (University of Cordoba). In all the stations, Hirst volumetric spore traps were used. They are located on buildings approximately 15 m above ground level. These traps have an autonomy of 7 days and collect pollen continuously with a given absorption flux, enabling daily and even hourly pollen concentration data to be obtained. Daily mean data are expressed in terms of pollen concentrations per cubic metre of air (gr/m^3). The aerobiological methodology recommended by the REA was used [15]. Pattern curves were constructed with 5-day

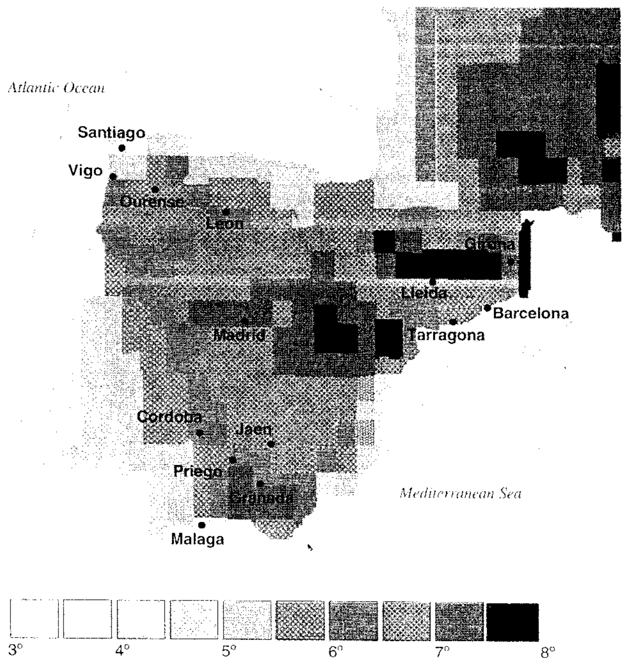

Figure 1. Predicted temperature increase for 2099 in the Iberian Peninsula (Regional Climate Model HadCM3A2a model). The study localities are indicated on the map.

moving-average values calculated from daily values. Graphs were plotted following the line-up method [32]. The Pollen Index (PI) was defined as the total pollen detected in the Main Pollen Season (MPS) of a given year. The start of the MPS was defined as the day on which 1 pollen grain/m^3 was reached wherever 5 subsequent days contained 1 or more pollen grains/m^3. The end was determined as the last day on which 1 pollen grain/m^3 was recorded wherever subsequent 5 days presented concentrations below this level [25]. Data from 1992-2000 were used to build prediction models. These were validated in 2001 and 2004, except in Leon and Priego. In Leon, models were validated in 2000 (not included in the model for Leon) and 2004, due to technical problems that interrupted sampling during the spring of 2001. In Priego, models were validated in 2001 (not included in the model for Priego) and 2002.

Meteorological data. The Spanish National Institute of Meteorology (www.inm.es) supplied daily meteorological data from its stations located nearest to the pollen traps. The Iberian Peninsula suffered a severe drought between 1990-1995, mainly affecting Mediterranean areas; as a result, the data were divided in 2 groups for the statistical analysis (except for the NW sites, unaffected by the drought). The extremely dry period, 1992-1995, and the usual climate period, 1996-2000.

Statistical analyses. The STATISTICA® software package was used in all analyses. For forecasting daily and annual pollen concentrations, a Spearman correlation test was performed previously to detect the chief variables affecting pollen values. Stepwise multiple regression analysis was performed in order to construct both daily and annual pollen forecasting models. Predictive variables were chosen by applying a Factor Analysis for Principal Components in order to avoid multi-colinearity. For daily forecasts, previous attempts by analysing the whole season revealed very weak and contradictory results, therefore 2 types of regression models were developed: Pre-Peak models (from the start date up to the maximum-value date); and After-Peak models (from the maximum-value date up to the end of the pollen season). Daily models were developed by constructing general equations comprising several years. For Mediterranean sites, 2 different groups of years were taken into account, to reflect the drought period (1992-1995; 1996-2000). Daily variables, such as weather data from the previous day and accumulated weather data from the previous 2-5 days, and previous and cumulative pollen counts up to the date for which the forecast was made were used as predictive variables. For PI forecasting models, the following were calculated: fortnightly minimum, maximum and mean temperature; fortnightly total rainfall; fortnightly evapo-transpiration and chilling hours based on daily data, to be used as independent variables in order to obtain predictive models for forecasting total annual pollen emission. Future start dates were calculated by applying future meteorological data to a previously-developed thermal forecasting Growing Degree Days (GDD°) method [27].

All predictive models were validated in years not included in the equations. For the daily model, 2 different equations were developed for Pre-Peak and After-Peak pollen curves. Since weather conditions from 2000-2004 were similar to those of 1996-2000 in the Mediterranean area, the proposed forecast formula for that period was used for validation purposes at years 2001 and 2004. Expected vs. actual data were compared graphically. The R2 coefficient and the Wilcoxon matched pairs test were performed between expected and actual data. Annual pollen models results were validated by calculating Root Mean Square Error and % Error.

Simulation model. Future meteorological data modelled by the Hadley Meteorological Centre including in the Intergovernmental Panel on Climate Change (IPCC), were used for estimating future pollination start dates. The data were obtained through a contract (Contract EPG 1/1/124) signed by Cordoba University and the Climate Impacts LINK Project (Hadley Centre). The present study also analyses the possible future consequences of this expected climate change on the annual amounts of released *Quercus* pollen, based on the forecast equations developed here. The model is a mathematical description of major elements and processes in the atmosphere, oceans and land surface comprising the climate system. By applying statistical downscaling the method adds fine-scale information. This technique uses observation in historical meteorological data sets and today's climate dynamic to derive relationships between large-scale climate variables and the surface climate at point

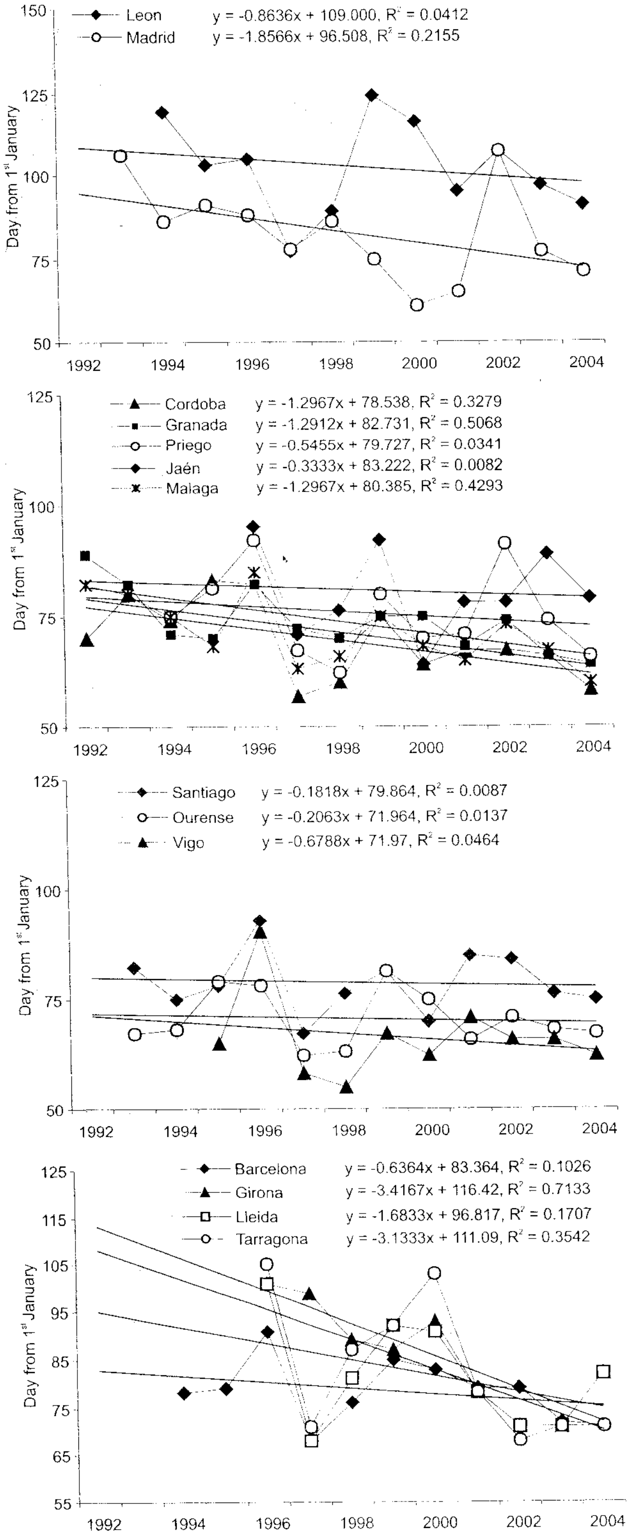

Figure 2. Start date variation during 1992-2004 at the 14 study localities (day of the year). Linear trend equation is also represented. The equation values and R^2 coefficient for each locality are also indicated.

locations [47]. The climate scenario applied for the end of the 21st century was the x2 CO_2 proposed by the IPCC, which assumes a 1% per year increase in CO_2 concentrations, which is the most probable expected increase for the next years. In this scenario, the HadCM3A2a Regional Circulation Model (RCM) developed by the Hadley Meteorological Centre provided us with future climate data. The RCM provided a horizontal resolution of 50 × 50 km grid cells, which allowed us to obtain a different climatic data base at all study sites (Fig. 1).

RESULTS

Pollen season start and Climate Change. The pollen season start date variation from 1992-2004 is shown in Figure 2. In this figure, the trend over the years is also plotted for each site. At all sites, the regression trend equation presented a negative slope coefficient, indicating that the start of the flowering season tended to be earlier in later years. This characteristic was more evident in inland central sites such as Madrid and Jaen. Due to the considerable year-on-year variation in start dates, equations are less well adjusted to a linear model, R^2 coefficients not being as close to 1. There was an evident gradual advance of the pollen season, which was more obvious in inland than in coastal areas, due to a greater warming in these study areas. Analysis of climate databases (National Institute of Meteorology) shows that temperatures recorded in the Iberian Peninsula have increased considerably. Figure 3 shows average temperature registered in the pre-flowering season (January-March), from 1951 to the present, at all study sites. The positive slope of the trend equations confirmed the increase in temperature.

Using the GDD° model [26, 27], it is possible to assess starting dates for years where climate data, but no pollen observations, are available. To ascertain the potential impact of future climate change on Mediterranean forest, future climate data, HadCM3A2a RCM, were applied to the GDD° model for the years 2025, 2050, 2075 and 2099. The predicted increase in temperature in the Iberian Peninsula varies among sites (Fig. 1). These differences are likely to give rise to marked geographical variations in the advance of phenology (Tab. 2). The predicted minimum advance will be in northwestern sites, such as Santiago, while in inland cities like León and Madrid flowering could take place up to 1 month earlier. In Table 2 it is possible to compare the detected advance from the beginning of the 90's until today, with the expected advance for the end of the present century.

Daily pollen concentrations. The curves showing daily pollen counts at the various study sites are shown in Figure 4. Generally speaking, the *Quercus* pollen season in the Iberian Peninsula lasted 3-4 months, depending on the vegetation and climate characteristics of the years and areas studied. Several peaks were observed in some cases, mostly due to the consecutive flowering of different species (see section: Description of Sites). Nevertheless, external factors such as spring rainfall or changes in wind direction or speed may also have contributed to a more irregular curve.

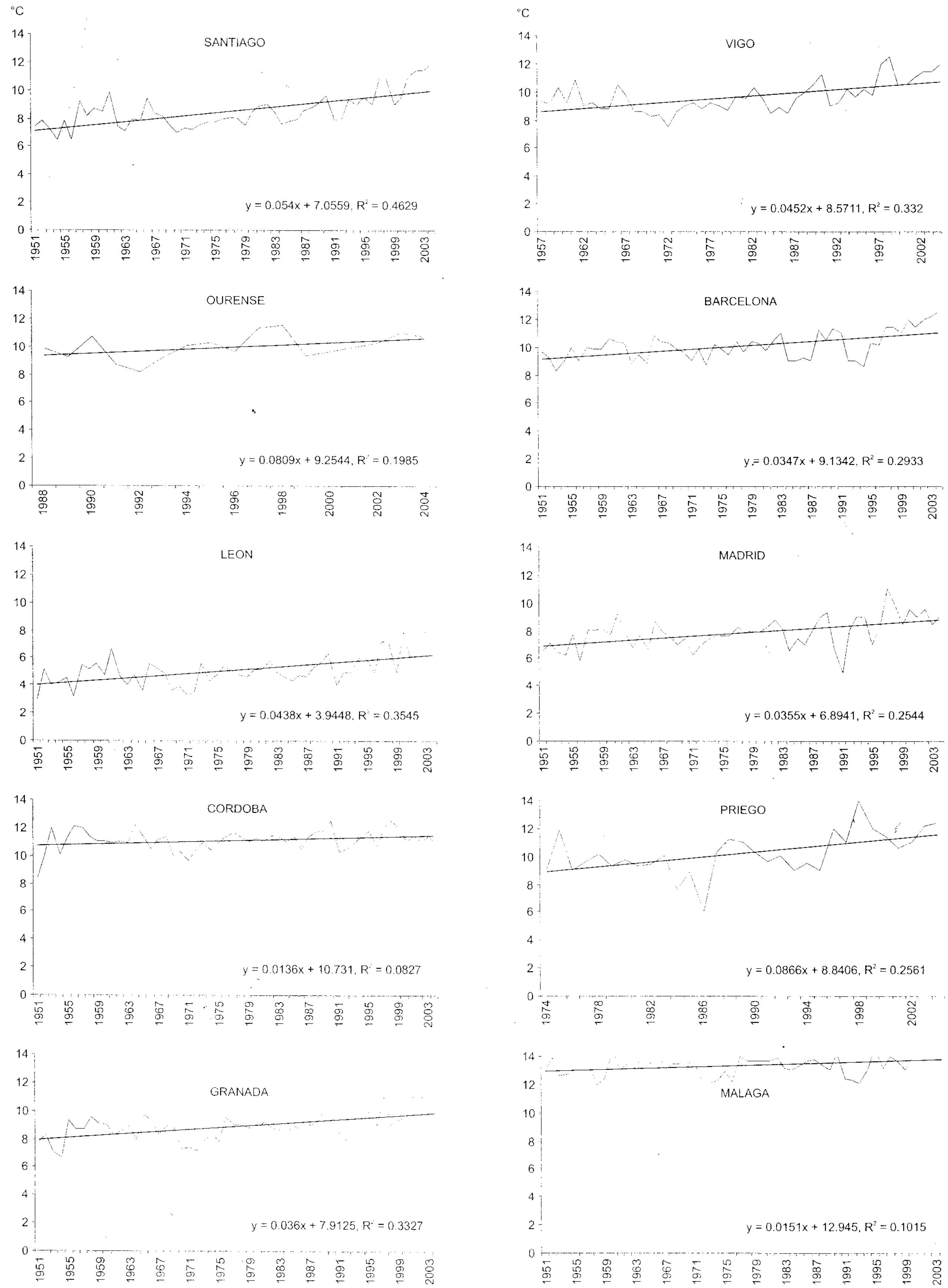
°C
SANTIAGO
y = 0.054x + 7.0559, R² = 0.4629
°C
VIGO
y = 0.0452x + 8.5711, R² = 0.332
OURENSE
y = 0.0809x + 9.2544, R² = 0.1985
BARCELONA
y = 0.0347x + 9.1342, R² = 0.2933
LEON
y = 0.0438x + 3.9448, R² = 0.3545
MADRID
y = 0.0355x + 6.8941, R² = 0.2544
CORDOBA
y = 0.0136x + 10.731, R² = 0.0827
PRIEGO
y = 0.0866x + 8.8406, R² = 0.2561
GRANADA
y = 0.036x + 7.9125, R² = 0.3327
MALAGA
y = 0.0151x + 12.945, R² = 0.1015

Table 2. Actual and expected start dates (day of the year). Advances between different periods are indicated in two last columns.

Site	Beginning 90's start date (d.y.)	Beginning 21st start date (d.y.)	Beginning 21st beginning 90's (days of difference)	2025 forecast start date (d.y.)	2050 forecast start date (d.y.)	2075 forecast start date (d.y.)	2099 forecast start date (d.y.)	2099 beginning 21st (days of difference)
Santiago	82	80	-2	80	79	77	77	-3
Vigo	74	65	-9	55	50	36	32	-33
Ourense	73	69	-4	54	48	33	29	-40
Barcelona	90	80	-10	77	76	74	75	-5
Girona		85		80	75	70	72	-13
Lleida		84		80	77	75	71	-13
Tarragona		90		80	76	76	75	-15
León	115	105	-10	90	64	47	31	-74
Madrid	106	82	-24	65	47	27	26	-56
Córdoba	90	80	-10	71	58	31	23	-57
Priego	91	75	-16	59	50	25	25	-50
Jaen		71		50	49	27	28	-43
Granada	82	75	-7	64	54	31	30	-45
Málaga	81	73	-8	68	54	43	34	-39
Mean	88	79	-9				45	-34

Similarities were detected between curves for sites located in the same climate region, probably due to a similar species spectrum and similar meteorological conditions. It was therefore possible to distinguish 4 general patterns in the NW, NE, Central, and Southern areas. Sites located in NW Spain (Figs 4a-4d), displayed low pollen concentrations with 1 peak right at the start of the season and another at mid-season. In the NE area, a lower peak is detected at the beginning of the season and another higher peak at the end (Figs 4e-4h). Very different pollen counts were recorded in the Central sites of Madrid (Fig. 4i) and León (Fig. 4d), Madrid values being substantially higher. Nevertheless, a similar pattern with 2 peaks (the higher one at the end of the season) was evident. Figures 4j-4n, showing *Quercus* pollen curves in Southern Spain, indicated high pollen counts, with several peaks during the season.

Daily pollen forecasting. Spearman's correlation test detailed results are not shown, due to their length and similarity to regression results. They revealed that temperature was the main factor affecting daily pollen concentrations at all sites. The correlation with temperature was positive in the Pre-Peak period, but negative in the whole-season analysis. These results were particularly evident at sites with longer pollen seasons. Moreover, the correlation analysis of pollen vs. wind data showed significant positive correlation coefficients at coastal sites on days when the wind came from inland; in contrast, the wind coming from the ocean prompted a decrease in airborne pollen. Similarly, in inland areas where *Quercus* pollen is influenced by the effect of valley-mountain winds, or where *Quercus* populations are located quite far from the monitoring site, wind direction and intensity also influenced pollen counts. Regression equations for many sites showed that daily temperature also exerted a positive effect on pollen data in the Pre-Peak period, while the results for the After-Peak period show that humidity and rainfall has a negative effect on airborne pollen. Moreover, previous pollen counts are more effective forecasting variables in the After-Peak period (Tabs 3, 4). Fewer year-on-year differences were observed at coastal sites than in inland regions.

Validation of daily pollen forecasts. Most of the proposed daily pollen forecasting models recorded significant statistical coefficients (Tabs 3, 4). Nevertheless, models were externally validated for 2001 and 2004, both graphically and statistically. Figure 5 shows the expected vs. observed daily pollen values in 2001 and 2004 for each site. Grey lines represent actual data and black lines represent expected data. Wider line represents 2001 data. The R^2 coefficient and the Wilcoxon matched pair test results from the statistical validation are shown in Table 5, p values > 0.01 indicate non-significant differences. The acceptable statistical results and similar patterns of the curves suggested that main daily pollen characteristics, such as the increase, peak or decrease periods, can be forecasted using the proposed equations.

Pollen Index forecasting. Annual Pollen Index (PI) at most sites were very high compared to pollen emitted by most of the anemophilous species presented in the study sites, particularly PIs detected in the Mediterranean area (Fig. 6). The Atlantic sites located in NW Spain had the lowest *Quercus* PI; higher amounts were recorded at

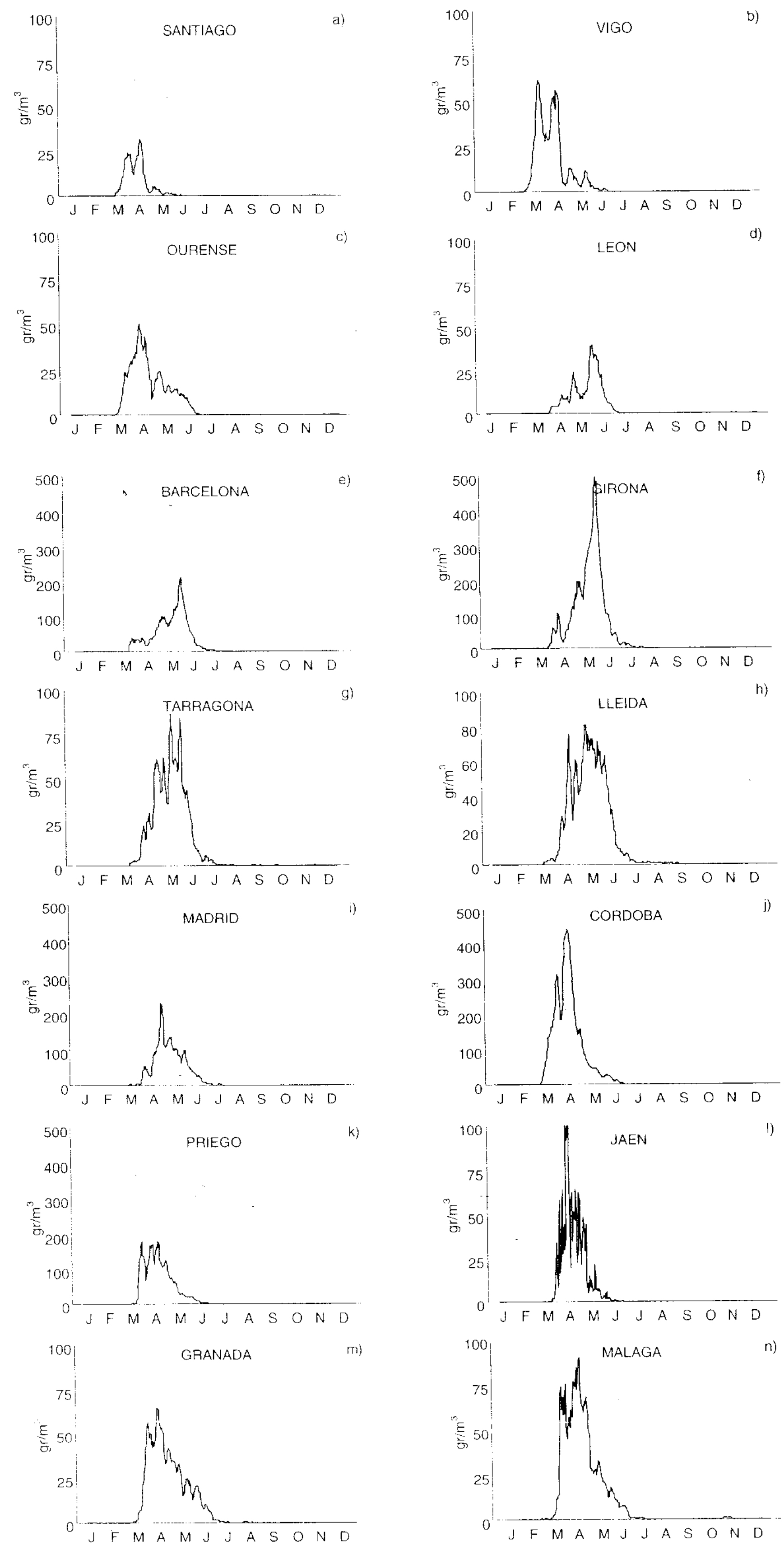

Figure 4. Average *Quercus* pollen season curves during 1992-2004 at the different sites. In the Y axis is represented the concentration of pollen expressed as grains per cubic meter (gr/m^3).

Table 3. Daily pollen forecasting equations from localities that suffered the drought period (1992-1995).

BARCELONA 94-95	Pre R^2 0.36 p<0.00	QUER: -9.9+0.17Q2+0.98Tmx
	After R^2 0.49 p<0.00	QUER: 20.08+0.11Q2-0.94Rf-0.83Rf-0.83Tmn
LEON 94-95	Pre R^2 0.82 p<0.00	QUER: 26.76+7.19WF3+3.85Rf1+2.17WF1
	After R^2 0.53 p<0.00	QUER: 28.3+0.27Q1-0.29H+0.32Rf1-0.24Tmx2
MADRID 93-95	Pre R^2 0.56 p<0.00	QUER: -61.18+6.33Tmn2+0.31Q1+1.17S5
	After R^2 0.75 p<0.00	QUER: 13.5+0.41Q2-0.23Q1-0.16Q3 +0.43H3-0.58Tmn2
CORDOBA 93-95	Pre R^2 0.68 p<0.00	QUER: -61.18+6.33Tmn2+0.31Q1+1.17S5
	After R^2 0.60 p< 0.00	QUER: -108.19+0.68Q1+1.6WF3-1.16WF4 +2.18S2
PRIEGO 94-95	Pre R^2 0.89 p<0.00	QUER: -231.2+2.05Q1+46.7WF4+4.1S3
	After R^2 0.70 p<0.00	QUER: 71.2+0.47Q1+0.14Q3-0.52H-1.5Tmn2
GRANADA 92-95	Pre R^2 0.75 p<0.00	QUER: -14.4+0.54Q1+1.27Tmx1+0.11Q2
	After R^2 0.73 p<0.00	QUER: 40.9+0.19Q2+0.29Q1-0.48H-0.84Tmn
MALAGA 92-95	Pre R^2 0.70 p<0.00	QUER: -192.7+0.178Q3+6.21Tmed+0.11Q2
	After R^2 0.77 p<0.00	QUER: 40.9+0.2Q2+0.3Q1+1.6WV-3.48Tmx +0.34WF4
JAEN 96-00	Pre R^2 0.65 p<0.00	QUER: -70.9+1.14Q1+20.4WF1+9.55WF4 -16.78Rf
BARCELONA 96-00	Pre R^2 0.57 p<0.00	QUER: -17.9+0.24Q2+3.84Tmn2-1.63Rf
	After R^2 0.52 p<0.00	QUER: 254.19+0.98Q1-0.73Q3+0.68Q2 -2.8Tm-22.8S
LEON 96-00	Pre R^2 0.67 p<0.00	QUER: -48.65+0.18Q3+3.14Tmx+0.09Q2 -0.13WV4
	After R^2 0.82 p<0.00	QUER: 7.98+0.15Q3-0.25Q1-0.43WV +0.66H-0.33Tmx2
MADRID 96-00	Pre R^2 0.71 p<0.00	QUER: -4.8+0.51Q1+0.59Q2-0.6WF4 +3.9S1
	After R^2 0.49 p<0.00	QUER: 99.2+0.25Q1+0.08Q3-4..5Tm2+0.03Q2
CORDOBA 96-00	Pre R^2 0.75 p<0.00	QUER: 432.9+0.8Q2-6.4H+9.9WV -8.4WF2
	After R^2 0.59 p<0.00	QUER: 42.18+0.6Q1-14.6Tm
PRIEGO 96-00	Pre R^2 0.94 p<0.00	QUER: 3.68+0.72Q1-1.6Q2
	After R^2 0.83 p<0.00	QUER: -70.5+0.72Q1-0.15Q2-6.44Tmn1
GRANADA 96-00	Pre R^2 0.81 p<0.00	QUER: -148.09+2.32Q2+0.82WC3+3.33Tmx2
	After R^2 0.65 p<0.00	QUER: 75.39+0.39Q1-0.9Tmn-0.79H -0.74Tmn2
MALAGA 96-00	Pre R^2 0.55 p<0.00	QUER: -305.8+0.6Q2+19.1Tmx-0.2Q3 +15.8Tmx1+4.2WF1
	After R^2 0.41 p<0.00	QUER: 77.4+0.25Q2-3.05Tmn2-0.3WF2 -2.23Rf
JAEN 96-00	After R^2 0.55 p<0.00	QUER: 25.6+0.42Q1-0.19H-3.4H1

Pre - Pre-Peak Season, Quer - *Quercus* pollen , Tmx - Maximum Temperature, Tm - Mean Temperature, WFn - Wind Frequency, n quadrant, Tmin - Minimum temperature, S - Sunshine Hours, Rf - Rainfall (mm), After - After-Peak season, Q - *Quercus* pollen , H - Relative Humidity, WV - Wind Velocity (km/h), C - Wind Calm, Index 1 - Data from the previous day, Index 2, 3, ... - Cumulated data from the two, three, ... previous days, gr/m^3 - Pollen grains by cubic meter.

Central and Southern sites. Regression analysis showed that rainfall and temperature (particularly maximum temperature) were the most important variables in Mediterranean areas, while both maximum and minimum temperatures prior to flowering were the most important parameter in Eurosiberian areas. There was a geographical gradient with respect to the months with the greatest influence in the forecast. Meteorological conditions 1 month prior to the pollen season had a decisive effect on models (Tab. 7).

Validation of Pollen Index forecasting. All regression models showed an adjusted regression coefficient (R^2) close to 1, with a probability value from 95-100% (Tab. 7). In Table 6, the plotting of actual vs. expected data from the validation in 2001 and 2004 yielded good results, with a Root Mean Square Error between actual and expected values of 16.2 in 2001 and 21.4 in 2004. An acceptable error under 25% was generally found. The difference was considerably smaller for Vigo, Ourense, Madrid, Cordoba, Granada and Malaga.

Climate Change model simulation. The average 4°-5°C rise in temperature produced by expected global warming prompted an increase in modelled flowering. Although the model did not predict significant changes in rainfall in the Iberian Peninsula, a increase of 5-10% in annual rainfall may occur in the Mediterranean area. This increase would be registered by means of more torrential rainfall episodes alternating with higher drought periods. The rate of future climate change simulated by the RCM varied significantly among Iberian areas (Fig. 1). Expected changes in temperature and rainfall could prompt a marked geographical variation in pollen production for *Quercus* species. The use of meteorological parameters for 2025, 2050, 2075 and 2099 in the validated Pollen Index forecasting models indicated that *Quercus* pollen production in the Iberian Peninsula could become significantly higher at most study sites (Tab. 8). The range of variation in PI as a function of the mean PI value (Pollen Index/Mean Pollen Index) is shown for the last decade. *Quercus* pollen production would record the maximum increase between 2050-2075, while few differences are

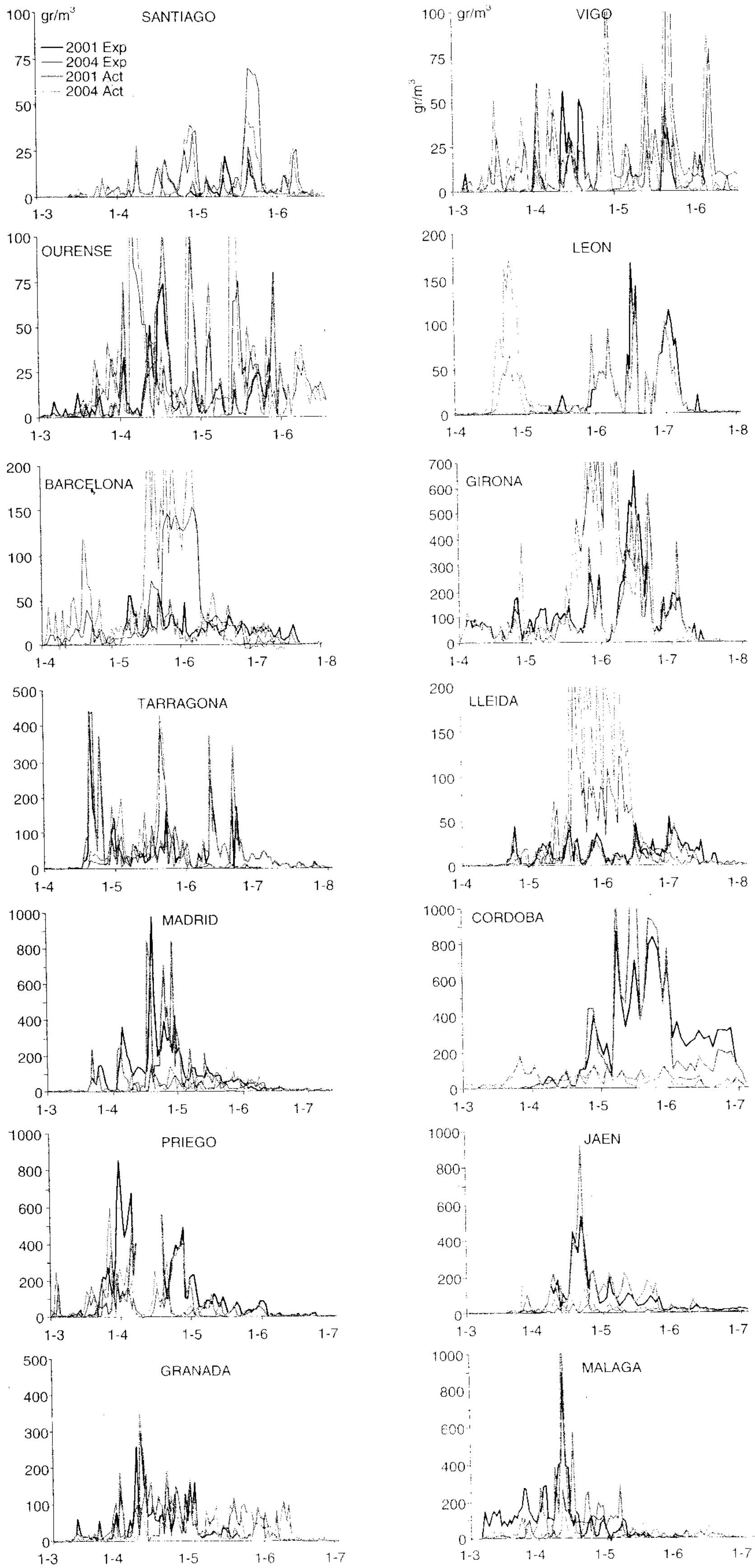

Figure 5. Daily pollen forecast validation for 2001 and 2004 (not included in the models). gr/m³: pollen grains by cubic meter. Grey line: actual data; black line: expected data. Dates are represented in x-axe.

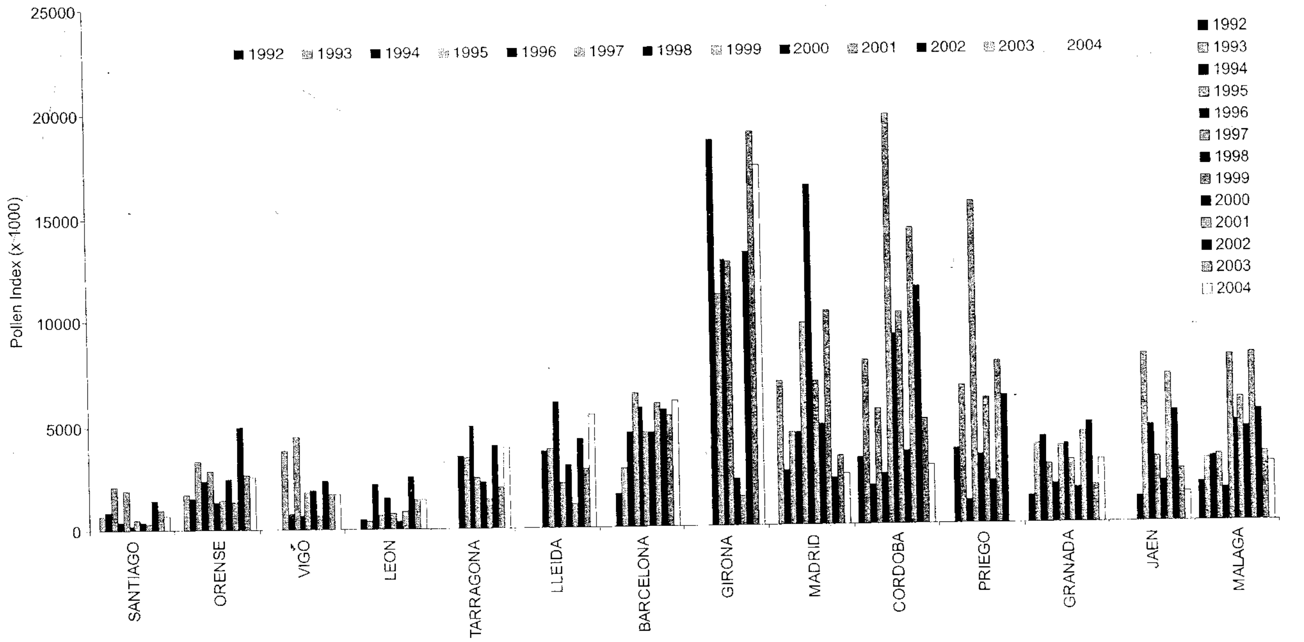

Figure 6. Evolution of annual *Quercus* Pollen Index in study areas.

expected for the last 25 years of the 21st century. Comparison with the variation factor expected in the future (Future Pollen Index/Mean Pollen Index) shows that expected PI will increase two and a half-fold from today's values. Climate simulation for the doubled CO_2 scenario produced different rates of pollen increase in different areas; these were lower in coastal areas than at inland sites, Mediterranean inland areas being the most affected.

DISCUSSION

Understanding pollen emission dynamics is fundamental for the characterization of potential allergens that may be of greater health relevance in both natural spaces and populated areas. *Quercus* airborne pollen counts at a given sampling station reflect reproductive phenology over an extended area [30]. Taking into account the number and distribution of the sites studied in the present paper, this research provides valuable information on the pollination dynamics features of *Quercus* genus in the Iberian Peninsula. The present results could be very useful for allergy physicians to know the main meteorological factors influencing on *Quercus* pollination dynamics. Moreover, the investigations carried out on the possible future consequences of climate change can give them a new vision of the possible changes in atmospheric allergens occurrence.

Results indicate that *Quercus* pollen season start has been advancing over recent years in the Iberian Peninsula. Results were similar to those obtained in a previous study involving fewer sites and years [27]. Other authors in northern Europe have reported similar findings for the *Quercus* pollen season [9]. With regard to other species, a progressive advance in flowering has also been observed in *Betula* [17], Poaceae [18], and *Alnus* and *Olea* [11] over the last 20 years. All these findings indicate that spring phenology in Europe is being significantly affected by global warming. On the basis of previous studies [26,

Table 4. Daily pollen forecasting equations from the north-west localities that did not suffer the drought period (Santiago, Vigo and Ourense). Results from localities with a shorter data base, (Girona, Lleida and Tarragona) also shown.

SANTIAGO 93-00	Pre R^2 0.84 $p<0.00$	QUER: -26.9+0.56Q1+0.4Q3+1.9Tm+1.8Tmx1
	After R^2 0.81 $p<0.00$	QUER: 46.7+0.51Q1-0.41H-0.32C+0.51Tmx2
VIGO 95-00	Pre R^2 0.83 $p<0.00$	QUER: -7.69+0.38Q2+0.30Q1-0.9WF3-1.59S2+2.7Tmx2
	After R^2 0.68 $p<0.00$	QUER: 7.61+0.28Q1-2.1WF1+0.05Q3-1.46WF4-0.29Rf3
OURENSE 93-00	Pre R^2 0.84 $p<0.00$	QUER: -26.9+0.72Q1+1.5Tmx+0.9S
	After R^2 0.81 $p<0.00$	QUER: 9.8+0.50Q1-0.09H-0.32Tmn1-0.37Tmx2
GIRONA 96-00	Pre R^2 0.69 $p<0.00$	QUER: -168.11+1.07Q1+15.39Tm-0.33Q2
	After R^2 0.73 $p<0.00$	QUER: 94.2+0.71Q1+0.14Q2-2.5Tmn2-1.2S2+1.08WV
LLEIDA 96-00	Pre R^2 0.54 $p<0.00$	QUER: -207.5+0.89Q1+9.68Tmx+2.88Rf3
	After R^2 0.51 $p<0.00$	QUER: 12.49+0.58Q1-3.6Tmn1-0.08Tmx+1.72Rf3
TARRAGONA 96-00	Pre R^2 0.53 $p<0.00$	QUER: -44.04+6.46Tmn+0.41Q1+5.93Tmn1
	After R^2 0.52 $p<0.00$	QUER: 19.86+0.59Q1+0.59Rf1-0.35H+0.19H1

Table 5. Daily pollen forecast validation for 2001 and 2004. R^2 and Wilcoxon pair test results shown. Differences significant at $p<0.01$.

Site	Year	R^2	Wilcoxon Matched Pairs Test*			
			N	T	Z	p level
Santiago	2001	0.55	59	160.50	1.23	0.21
	2004	0.68	122	598.00	1.24	0.21
Vigo	2001	0.72	116	214.00	1.42	0.15
	2004	0.46	107	1,306.00	2.85	0.00
Ourense	2001	0.77	116	1,097.00	1.73	0.08
	2004	0.65	115	2,116.50	0.77	0.44
Leon	2001	0.74	91	216.00	1.83	0.66
	2004	0.72	81	359.00	2.85	0.00
Barcelona	2001	0.68	122	515.50	1.58	0.11
	2004	0.64	106	930.00	1.83	0.07
Girona	2001	0.73	121	857.50	3.65	0.03
	2004	0.80	113	1,306.00	0.24	0.81
Tarragona	2001	0.53	122	970.00	2.40	0.02
	2004	0.83	92	545.50	1.23	0.26
Lleida	2001	0.40	122	1,284.00	3.20	0.01
	2004	0.61	106	1,337.50	1.68	0.09
Madrid	2001	0.27	123	1,201.00	2.00	0.04
	2004	0.34	122	2,224.50	0.38	0.71
Cordoba	2001	0.78	85	601.00	1.21	0.22
	2004	0.65	98	1,306.00	2.33	0.08
Priego	2001	0.58	112	1,309.00	5.00	0.01
	2002	0.45	77	1,099.50	1.55	0.12
Jaen	2001	0.79	91	783.00	1.16	0.24
	2004	0.23	104	184.00	4.14	0.00
Granada	2001	0.79	127	1,033.00	0.05	0.96
	2004	0.43	119	493.00	1.97	0.06
Malaga	2001	0.52	131	1,407.00	1.53	0.13
	2004	0.40	115	2,839.00	0.64	0.52

* Marked differences are significant at $p<0.05$

Table 6. Annual Pollen Index forecast validation for 2001 and 2004. The Expected (Exp) and Actual (Act) Pollen Index (PI), and difference between them are shown. The fifth column indicates the percentage of error (%Error) in relation with the actual Pollen Index. The Absolute Mean, Standard Deviation (SD) and Root Mean Square Error (RMSE) are also shown.

Site	Year	Expected PI	Actual PI	Dif (Exp-Act)	%Error
Santiago	2001	209	282	-73	25
	2004	792	685	107	15
Vigo	2001	520	629	-109	17
	2004	1,972	1,742	-230	1
Ourense	2001	1,386	1,387	-1	0.07
	2004	2,168	2,578	410	15
Barcelona	2001	2,424	5,965	-3,541	59
	2004	4,289	6,002	-1,713	28
Tarragona	2001	1,410	1,412	-2	0.14
	2004	2,647	3,931	-1,284	32
Girona	2001	1,837	1,411	426	30
	2004	20,933	19,113	-1,820	9
Lleida	2001	1,122	1,119	3	0.26
	2004	3,225	5,429	-2,204	40
Leon	2000	1,197	822	-375	41
	2004	1,244	1,405	-161	11
Madrid	2001	12,564	10,307	2,257	19
	2004	2,422	2,525	103	4
Cordoba	2001	13,324	14,260	-936	6.5
	2004	2,990	2,891	-99	3
Priego	2001	8,024	7,774	-250	3
	2002	4,272	6,158	-1,886	30
Jaen	2001	5,931	7,161	-1,230	17
	2004	896	1,931	-1,035	50
Granada	2001	5,235	4,429	806	17
	2004	3,992	4,303	-311	7
Malaga	2001	6,224	8,156	-1,932	23
	2004	3,195	2,823	372	13
Absolute Mean	2001			852	**17.4**
	2004			838	**18.4**
SD	2001	4,367	4,372		
	2004	5,026	4,565		
RMSE	2001			**16.2**	
	2004			**21.4**	

27] it is clear that the *Quercus* start date in the Iberian Peninsula is strongly determined by temperature, therefore, if our climate continues to change as projected, the start of the *Quercus* pollen season would continue to advance.

Comparative aerobiological studies of sites with different climatic characteristics give us a global idea of the different behaviour of airborne pollen under specific meteorological conditions in large areas [19]. Regarding *Quercus* daily pollen dynamic in Spain, the seasonal floral phenology of the various *Quercus* species presented at each site determines the shape of the pollen curve. The curve was fairly similar for the 3 study sites in the NW area: Santiago, Vigo and Ourense. In Southern Spain, the 3 species present in lower altitude areas (Cordoba and Malaga), *Q. ilex* subsp. *ballota*, *Q. coccifera* and *Q. suber* have consecutive flowering periods that gave rise to a 3-peak pattern, the highest being the *Q. ilex* subsp. *ballota* peak. In higher altitude areas, such as Jaen, Granada and Priego, the great abundance of *Q. ilex* subsp. *ballota* accounted for almost all pollen grains reflected in the curve. In these areas, *Q. ilex* subsp. *ballota* populations growing at different altitudes caused consecutive peak pollination patterns; in this case, topography was responsible for the irregular curve.

The specific aerobiological behaviour of *Quercus* pollen has been studied in different parts of Europe and the USA from a descriptive standpoint [9, 25, 35, 37, 50]. However, no studies have been performed on the forecasting of airborne *Quercus* pollen levels. The daily forecasting results presented here indicate that the main variables were temperature and hours of sunshine, with a

Table 7. Annual Pollen Index (PI) forecasting regression equations.

Site	Regression equation	R^2	p level
Santiago	PI=-22885+19(RfF1)+460(MeanF2)+1086(MxJ2)+270(MxJ1)	0.99	0.02
Vigo	PI=11345+4(RfJ2)+1610(MnF2)+434(MnJ2)-1652(MxF2)	0.99	0.02
Ourense	PI=2905+5.4(RfJ1)+3.6(RfJ2)+(MnF1)-274(MnJ1)-238(MeanF2)	0.99	0.03
Barcelona	PI=4401-61(RfF1)+28(RfJ2)-150(Rf2)	0.99	0.00
Tarragona	PI=36344-2423(MxE2)+228(RfF1)	0.99	0.00
Girona	PI=35221-2023(MxM1)+1238(MeanF2)-76(RfJ1)+40(RfJ2)	0.99	0.00
Lleida	PI=5075-45(MxM1)-139(MnM1)-121(RfM1)+205(RfF1)	0.99	0.00
Leon	PI=9047-888(MxJ2)+8(MxF2)+5.3(RF1)	0.98	0.00
Madrid	PI=-26098+1955(MnF1)+3909(MnM1)+996(MeanJ1)+1005(MeanJ2)	0.99	0.02
Cordoba	PI=32909+1652(MxF2)+1082(MeanF1)+100(RfF1)+415(MnE2)	0.98	0.00
Priego	PI=757+1367(MnF2)+52(RfF2)	0.99	0.01
Jaen	PI=-37045-3571(MeanM1)+6664(MnM1)+2391(MxJ1)	0.99	0.02
Granada	PI=3731-1002(MeanF1)+1002(MnF1)-64(RfM1)-21(MeanF2)+10.6(RfJ1)-170(MeanJ1)	0.99	0.05
Malaga	PI=5576+648(MxF2)+9.4(RfJ1)+409(MeanF2)+303(MxM1)	0.99	0.00

RfJ - Rainfall January , RfF - Rainfall February , RfM - Rainfall March , MxJ - Maximum Temperature January, MxF - Maximum Temperature February, MxM - Maximum Temperature March, Index 1 - 1st fortnight, MeanJ - Mean Temperature January, MeanF - Mean Temperature February, MeanM - Mean Temperature March, MnJ - Minimum Temperature January, MnF - Minimum Temperature February, MnM - Minimum Temperature March, Index 2 - 2nd fortnight.

Table 8. Average Pollen Index (PI) from last years (1992-2004) compared with the calculated future PI for 2099 at different sites of the Iberian Peninsula. Range and average value of variation factors from the last decade is compared with the adjusted increase factor expected for the end of the 21st century.

Site	Last decade Mean Pollen Index (MPI)	Last decade Range of Variation Factor (PI1n/MPI)	Last decade Average Variation Factor	PI 2025	PI 2050	PI 2075	PI 2099	Variation Factor (PI 2099/MPI)
Santiago	825	(0.3-2.5)	1.4	870	870	880	880	1.1
Vigo	2,044	(0.4-2.2)	1.3	2,100	2,100	2,200	2,250	1.1
Ourense	1,500	(0.9-2.2)	1.5	2,050	5,600	9,650	10,800	7.2
Barcelona	4,500	(0.4-1.2)	0.8	5,100	5,900	6,200	6,100	1.4
Tarragona	3,000	(0.7-1.4)	1.05	3,510	4,100	4,650	4,640	1.5
Girona	9,850	(0.2-1.7)	0.95	10,530	13,730	14,800	15,410	1.5
Lleida	3,500	(0.4-1.7)	1.05	5,080	7,550	7,900	8,000	2.3
Leon	900	(0.5-2.3)	1.4	2,500	3,740	3,970	4,100	4.5
Madrid	7,500	(0.4-2.0)	1.2	9,000	16,750	21,200	23,800	3.2
Cordoba	8,000	(0.3-2.3)	1.3	11,210	16,600	23,500	24,500	3.1
Priego	6,000	(0.3-2.4)	1.35	6,400	10,500	17,320	17,600	3.0
Jaen	4,400	(0.3-1.8)	1.05	6,500	7,540	8,500	9,800	2.2
Granada	3,200	(0.5-1.3)	0.9	4,870	5,600	5,600	5,600	1.8
Malaga	5,000	(0.4-1.6)	1	5,090	5,500	6,210	6,600	1.3
Absolute Mean	4,300	(0.4-1.9)	1.16	5,340	7,580	9,470	10,005	2.5

MPI - Mean Pollen Index, PI - Pollen Index, PI1n - Pollen Index from each study year.

positive effect on daily *Quercus* pollen variation. It was noticeable that at many sites, daily temperature variables showed positive coefficients in the Pre-Peak equations, whereas previous results for the whole season displayed significant negative coefficients. The extensive length of the *Quercus* pollen season makes coincident the increase in temperature in late spring/early summer with the end of the season, when decreasing pollen concentrations were recorded due to the intrinsic phenology of the plants. Due to this fact, different meteorological factors influenced in the 2 pollination periods. Results showed that different meteorological factors affected in the 2 periods. In the Pre-Peak period, temperature variables positively affect the pollen liberation, whereas in the After-Peak period, Humidity and Rainfall influence the atmospheric dynamics of the pollen already liberated.

Moreover, the use of previous pollen records has proved to be a very useful tool in pollen forecasting overall in the After-Peak period. The use of this sort of data is recommended in taxa with a recurrent pollen curve year after year, such as *Quercus* [6, 43]. In general, the validation of the proposed models was performed in 2 years in order to confirm the results. The years from 2001-2004 were climatically similar to the 1996-2000 period, and drought years were not detected. 2001 and 2004 years were randomly chosen. Validation of the daily forecast models for 2001 and 2004 showed that the main daily pollen characteristics can be accurately forecasted.

A number of authors have studied inter-annual Pollen Index variations in different species in broad geographic zones, such as all Europe [55], England [18], Italy [21] and the Iberian Peninsula [25, 34]. In general, these authors reported that bio-geographic and climatic characteristics, as well as human action, can affect air-borne pollen counts in each area. In the present study, the highest pollen concentrations were detected in different years, depending on the area, although fewer inter-annual differences in pollen counts were observed at coastal sites than in inland study areas; this may have been due to the lower degree of climate variation in these areas. In general, the annual PI tended to decrease in the early years of sampling (1992-1995) due to the drought. Later, annual PI increased due to recovery of these trees. Nevertheless, this recovery was not detected in the first "post-drought" year (1996) as might be expected, but 2 years later, in 1997. The extreme drought period weakened oaks, slowed down vegetative growth, and prompted biomass loss. The wetter 1995-1996 winter probably led to a recovery of vegetative biomass and to strong production of vegetative buds instead of floral structures. This phenomenon was clearer in the south of the Peninsula, where the shortage of rain was most acute. The same trend has been observed in other species in the Peninsula, such as *Olea europaea* [13] or *Platanus* spp. [14].

In 1997, 1998, 2003 and 2004 the highest PI was recorded in the southern cities, whereas in the northwest area – unaffected by the drought – the highest concentrations were detected in 1995. During this year, a very high concentration of *Quercus* pollen was also observed in England [9]. Weather conditions over previous months have been shown to exert a remarkable effect on the intensity of *Quercus* flowering. Rainfall during the month prior to the pollen season has been highlighted as the parameter making the greatest contribution to pollen production. In other species, such as the olive which flowers in late spring, studies report that in Cordoba (southern Spain) rains make the greatest contribution to flower production in March [23], whereas in Perugia (Central Italy) the rain effect on flowering intensity is strongest in May [20]. In the Cupressaceae family which flowers in winter, it has been reported that the minimum temperature in November and rainfall in November and December were the variables exerting the greatest influence on the PI [22]. In other models designed for trees with clear biennial patterns, such as *Betula*, PI values from the previous year have been included as independent variables, as well as temperatures in the current year [12]. In the results obtained here, the variables with greatest influence on total *Quercus* pollen counts were rainfall and maximum temperature in Mediterranean localities, and minimum temperatures in Eurosiberian Region sites or these influenced by its climate. This may be due to the fact that Mediterranean species flower during early spring when minimum temperatures do not vary significantly from winter, whereas Eurosiberian species flower in late spring when minimum temperatures are much higher and go a long way towards determining the development of floral structures. The gradients for the most influential months, i.e. weather characteristics 1 month prior to flowering, have the strongest influence on oak flowering intensity.

In Spain, 21.5% of the population suffer from pollen allergy which involves a high number of sick leaves [2]. Annual allergy costs for the Spanish Government rise above 1,500 million Euros [39]. Advance knowledge on the intensity of the pollen season would help allergy physicians and allergy sufferers to better plan and manage allergy treatments.

Prentice *et al.* [49] examined the implications for future CO_2 concentrations. Projected increase on CO_2 concentration by 2099 ranged from 1.9-3.5 times. Nevertheless, the most expected CO_2 increase is projected to rise 2 times [10]. The implementation of future climate data presented in this work was carried out under x2 CO_2 scenario. Results indicate that the *Quercus* species in the Iberian Peninsula are already responding to climate warming. Changes in temporal occurrence of atmospheric allergens could have important clinical consequences [3]. The floral phenology of *Quercus* species in the Iberian Peninsula is suffering the rising spring temperatures in the Mediterranean area, like the phenology of *Betula* and *Alnus* in colder biomes, where climatic warming is already having a visible impact on vegetation [8, 16, 41, 54]. Moreover, floral phenology of other tree species in the Iberian Peninsula is being affected. It has been detected that *Olea* flowering season has suffered a general advance in the Iberian Peninsula [24]. This advance has been shorter than that observed for *Quercus* species, probably due to the higher dependency on temperature of early spring tree species flowering date. For late spring species, such as olive, photoperiod and rainfall also influence the flowering date [24]. The increase of temperature is probably affecting the flowering of many other Iberian species, especially species like *Platanus* or *Ulmus*, which have shown a clear response to temperature before flowering [1]. Modelling future Ombrothermal Indexes combining Temperature, Rainfall, Aridity and Continental Indexes for the inland central area of Leon suggest that the next 50 years will not see significant changes in seasonal rainfall distribution – a major factor for climate-related plant species [51]. The study also

predicts an increase in temperature of 1-2°C over the next 50 years, which will lead to accelerated vegetative and flower growth and an advance in flowering dates. The results of that local study agree with those reported here for the Leon area.

A number of authors have reported that the increase in airborne pollen counts recorded by most European aerobiology stations over recent years may be due to this climate warming [33, 47]. Some authors, using a vegetation biogeochemical model (BIOME3) where torrential rainfall increases 5-10% in the Mediterranean area, indicated that future climate conditions will lead to the spread of an evergreen forest in the Mediterranean [7, 31]. This hypothesis, taken in conjunction with the models proposed here, suggests an increase in the evergreen *Quercus* pollen of the Iberian Peninsula. The pollen season of these trees will start earlier, and will also prompt higher pollen emissions throughout the Mediterranean area. These effects would be more evident in inland areas as Madrid, Leon, Jaen or Cordoba.

The present paper, together with other studies performed in different anemophilous species, show considerable evidence to suggest that climate change, specially temperature increase, will have, and has already had, impacts on aeroallergens. Climate change effects include impacts not only on pollen amount and pollen season, but also in plant and pollen distribution and other plant attributes. For this reason, theoretical models, such as these here presented, must be understood only as a partial approach to the future environmental conditions that could also be modified by deforestation, or land use changes. There are many research challenges to a more complete understanding of the impacts of climate change on aeroallergens and allergic diseases [3]. In-depth studies covering main allergenic pollen species in Europe should be carried out in order to obtain a full idea of the possible effect of climate change on the pollination dynamic characteristics. Therefore, new efforts on this subject should be made by public health authorities and allergy physicians in order to be aware of these changes in the environment to adapt allergy treatments.

CONCLUSIONS

Quercus floral phenology has been advancing over the last few years; pollen seasons in the Iberian Peninsula have, since the beginning of the 90s, been starting an average of 2 weeks earlier.

Quercus pollen-curve characteristics varied between different bio-geographical zones, but were similar for sites with similar climate and species. It was therefore possible to distinguish 4 general patterns in the NW, NE, Central, and Southern areas. In the Mediterranean area, minimum and maximum temperatures were the main parameters influencing daily pollen-count. Maximum temperature was the most influential factor in the Euroiberian area.

The Pollen Index varied considerably between sites and years, depending on previous weather conditions. In the Mediterranean area, rainfall and temperature (particularly maximum temperature) prior to flowering were the most important variables. Both maximum and minimum temperatures were the major parameters in the Euroiberian area.

Results of external validation of daily and annual forecasting models suggest the possibility to use *Quercus* pollen forecasts in future in the Iberian Peninsula.

Using the RCM climate-change model, it may be suggested that the impact of future climate variation on Iberian *Quercus* floral phenology would be different depending on the areas. It would be more marked in inland than in coastal areas. In general, the pollen season will start earlier and will also prompt higher pollen emissions throughout the inland Mediterranean area in general. Thus, the likelihood is that climate change will modify the time of the occurrence of human oak-pollen-allergy problems.

Using climate predictions from the RCM climate, our results would suggest that, as climate warms, the Iberian *Quercus* pollen season will start earlier and will also prompt higher pollen emissions, with the strongest effects in inland areas. Therefore, the likelihood is that climate change will intensify human oak-pollen-allergy problems.

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